

Impact radiologique liés au transport par route de matières radioactives en Espagne

Radiological impact associated with the transport by road of radioactive material in Spain

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RESUMÉ

Les questions en relation aux transports des matériaux radioactifs sont d'actualité, due à l'incrément de la mobilité du matériel en relation au cycle de combustible nucléaire, au compromis avec l'environnement et la protection des personnes, ainsi que les normes légales régulatrices. L'impact radiologique associé à ce type de transport a été évalué par le biais du nouvel outil de traitement de données, qui peut être d'utilité et servir comme documentation complémentaire de celle puisé dans le cadre de la réglementation légale de transport. Ainsi, ayant connaissance du niveau de radiation à un mètre du transport et en choisissant la route, nous obtiendrons les impacts associés, tel que, la population affectée, la dose reçue par la personne la plus exposée, l'impact radiologique global, la dose reçue par la population durant le trajet et le possible détriment de leur santé. Comme conclusion on observe que les émissions de radiation ionisantes en provenance du transport de matériel radioactif par route en Espagne, n'est pas significatif à l'heure de généré des effets adverse pour la santé humaine et son impact radiologique peuvent être considéré comme méprisable.

SUMMARY

Questions relating to the transport of radioactive materials are very much an issue of current interest due to the increasing mobility of the materials involved in the nuclear fuel cycle, the commitment to the environment, the safety and protection of persons and the corresponding regulatory legal framework. The radiological impact associated with this type of transport has been assessed by means of a new data-processing tool that may be of use and serve as complementary documentation to that included in transport regulations. Thus, by determining the level of radiation at a distance of one metre from the transport vehicle and by selecting a route, the associated impacts will be obtained, such as the affected populations, the dose received by the most highly exposed individual, the overall radiological impact, the doses received by the population along the route and the possible detriment to their health. The most important conclusion is that the emissions of ionising radiations from the transport of radioactive material by road in Spain are not significant as regards the generation of adverse effects on human health and that their radiological impact may be considered negligible.

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1. Introduction

In the transport of the radioactive materials involved in the nuclear fuel cycle or of other such materials (e.g. nuclear fuel, inspection equipment, radioactive sources, radioactive wastes, etc.), the safety of the materials, the protection of persons (Law 31/95, 1995), commitment to the environment and compliance with the legal standards are of fundamental importance.

The following questions may be asked: Which are the busiest routes? What radiological impact is generated on the environment or on persons, the occupants of a private vehicle, the general public ...?

In Spain there are more than 10.000 kilometres of “radioactive transport routes”. Nuclear fuel is transported by road from the Juzbado fuel assembly manufacturing facility in the province of Salamanca to the nuclear power plants, and from here the low and intermediate level radioactive wastes generated are transported, also by road, to the El Cabril disposal facility in the province of Córdoba. The transport operations to or from the nuclear power plants and involving the equipment and materials necessary for the correct operation of these facilities should also be taken into consideration.

2. Regulation of the road transport of radioactive material

In Spain the transport of radioactive material is regulated by a series of internationally applicable standards based on the Regulation for the Safe Transport of Radioactive Materials of the International Atomic Energy Agency, IAEA (ADR, 2007). In all these standards the safety of the transport operations is based fundamentally on the packaging, of which there are different types (Exempted, Industrial, Type A, Type B and Type C) and design criteria are established relating both to the level of activity and to the physical form of the radioactive materials contained therein. Also detailed are the precautions to be taken as regards signposting and labelling and the requirements relating to the packaging during transport.

In order to ensure radiological protection and the prevention of environmental risks, limits are applied in relation to the intensity of the radiation and the contamination on the surface of the packaging and vehicles. The levels of activity transported area also limited. Another fundamental requirement is the supervision and control carried out by the safety counsellors (RD 566,1999).

3. Assessment methodology

The methodology used in preparing this work is based on the ‘descriptive-explanatory’ method, which allows data to be observed and acquired by means of the ‘case study’ approach (Chetty S., 1996; Yin R., 1994). The aim of this method is to systematically describe the logistics of the road transport of radioactive material and the radiological impact associated with it by using direct and indirect sources. For the first of these, several companies have collaborated (the Spanish nuclear power plants: Cofrentes, Garoña, Vandellós II, Trillo, Almaraz, Ascó (Spanish NPP, 1995) and José Cabrera, the latter having been declared definitively shut down, the national radioactive waste

management company Empresa Nacional de Residuos Radiactivos (ENRESA), installations such as Tecnatom, S.A. and the transport company E.T.S.A.. In order to identify the regulations governing permits and arrangements for radioactive material road transport operations, official organisations (Spanish Nuclear Regulatory Body) were also consulted.

The nuclear fuel cycle has been selected due to its being the most representative area as regards radioactive transport operations, because of the control exercised over it by the competent authorities, the particularly important set of standards by which it is governed and for its significance for national energy development.

In Spain new fuel assemblies are transported to the nuclear power plants. Here, preventive maintenance and inspection activities are carried out in order to ensure the correct operation of the facilities, and the equipment and materials used occasionally become contaminated, as a result of which they must be transported as radioactive materials.

To a lesser extent, specimens and samples of irradiated materials and sources of different isotopes from research centres, used in different tests to observe the behaviour of different materials in response to ionising radiations, are also transported as radioactive materials.

Radioactive wastes and waste products or materials (Law 54/97, 1997), are also transported. These materials contain or are contaminated with radionuclides in concentrations of activity that sometimes exceed the levels established in the legislation. Low and intermediate level wastes (GRWP, 2006), have low concentrations of radioactive material, due fundamentally to the presence of radionuclides with a half-life of under 30 years and very low and limited contents of long-lived elements. High level wastes, mainly consisting of the spent fuel from the nuclear power plants, are temporarily stored underwater in the plant pools for cooling and, since 2002, in metallic dry storage casks at the so-called individualised temporary storage (ITS) facilities, as a result of which this type of waste is not currently transported.

4. Dose assessment

Although the aim of this paper is to assess the radiological risk for persons resulting from the emission of ionising radiations associated with the transport of radioactive materials, we are also interested in gaining insight into the probability of risk to their health. Ionising radiations produce ionisation upon passing through the tissues of living organisms. This ionisation upsets the chemical behaviour of the constituents of the affected cells; some of these may regenerate while others may be damaged. It should be borne in mind that the exposed individual is not bound to suffer cancer or genetic injury, but simply runs a higher risk of so doing than non-irradiated persons. This risk increases with dose (Ortega X, *et al.*, 1988).

In order to be able to make generally applicable estimates, the International Commission on Radiological Protection recommends a series of risk values, obtained for the population of different countries and continents (Publication ICRP, 1999), “the average of these values as regards the probability of death by cancer is 5% per *Sievert* in a population of all ages, as long as the dose and dose rates in question are low”.

The Spanish Nuclear Regulatory Body (CSN) and the Carlos III Institute of Health (ISCIII) have carried out an “epidemiological study of the possible effects of ionising radiations arising from the operation of the Spanish nuclear fuel cycle nuclear and radioactive facilities on the health of the population residing in areas surrounding such installations” (Nuclear Safety Council, 2010), which we shall use as a reference.

5. Radiological impact of the transport by road of radioactive materials in Spain

The negative impact associated with this type of transport affects the environment, especially the living organisms exposed, and in particular the health of persons.

Work began with the selection of a representative year in terms of the volume of transport operations performed (2007, the year of heaviest traffic associated with the nuclear fuel cycle in the last decade) (Chetty S., 1996), a conservative situation being chosen for comparison with other years of interest. The level of traffic in question was the result of the scheduled refuelling outages that occurred at all the Spanish nuclear power plants during the year, a situation that will not occur again until 2011. There were a larger number of transport operations involving fuel, inspection equipment and mainly low and intermediate level radioactive wastes arising from the maintenance work performed at the nuclear power plants.

The more than 6,000 items of data received were processed using computers, generating tables, graphs and transport routes (among the most important and those that generate the highest impact are the routes for the transport of the low and intermediate level wastes from the six nuclear power plants to the disposal facility at El Cabril in Córdoba).

(Fig. 1) shows the most active transport routes in Spain, these being the A-2, A-3 and A-5 highways, the rest being considered lower transit or even secondary routes.

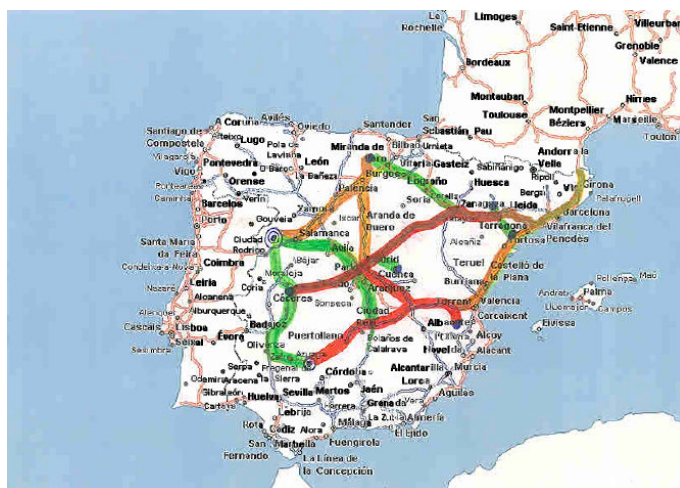


Figure 1 - Radioactive material transit routes

In total “**24 radioactive material transport routes**” were considered. During the year studied, “**243 transport operations**” were performed and “**12,865 km. covered**”. The populations and provinces exposed, the total distance covered (124,554 km. for all the shipments), the time taken (1,554 hours for all the transport operations) and the

population per route were identified (example: the most significant route is from La Junquera on the border with France to Cofrentes NPP, with an exposed population of 10,048,888 inhabitants. The least significant route studied was that linking the fuel manufacturing facility at Juzbado to Almaraz NPP, with an exposed population of 756,902 inhabitants). The national population is also considered in the study; in this last case only the towns located on the transport routes are taken into account, thus leaving out the regions of Galicia, Cantabria, the Basque Country, Navarre and Murcia, as well as a large part of Andalusia, since no transport operations are carried out on the roads in these areas.

Taking into account as the probability of impact, which is indicated in the lower margin of (Table I), **“Radiological impact associated with the transport by road of radioactive material in Spain (2007)”**, it may be appreciated that the total environmental impact caused by ionising radiations, as the sum of all the transport operations performed by the time taken on route and considering the levels of radiation at a distance of one metre from the transport vehicle, will amount to **46.64 mSv·y⁻¹**, similar to the annual legal limit permitted in Spain for workers professionally exposed to ionising radiations (50.00 mSv·y⁻¹). It may be observed that the greatest impact, 42.00 mSv·y⁻¹, occurs in the transport of radioactive waste, the transport of fresh fuel implying a lower level of 15.92 mSv·y⁻¹.

However, in the emission of ionising radiations there is a process of attenuation depending on distance: as the distance from the source of emission increases, the level of radiation decreases in inverse proportion to the square of the distance (Tanarro, A. 1986). This attenuation occasionally leads to confusion with the natural ambient background radiation of the area.

Continuing with (Table I), it may be seen that the dose potentially received by the most exposed individual, who will be the driver or passenger of a private vehicle coinciding on route with the radioactive material transport vehicle and overtaking the latter on three occasions (15 seconds to overtake on three occasions on long journeys lasting 7 hours), will amount to 1.36 µSv·y⁻¹. This is comparable to the findings of the study performed in Switzerland (Tanaboylu, K. *et al.*, 2001) which establishes that the radiation dose received by a person located 10 metres from a passing vehicle transporting spent nuclear fuel and travelling at a speed of 20 km/h. would amount to just 0.025 µSv.

The impact on the “exposed group” located in the regions through which this type of transport passes (national impact), applied to the entire population residing in the different towns and provinces (23,419,367 inhabitants) (INE, 2008), on the basis of the number and route of the transport operations and the distance from the vehicles involved, will be 1.1·10⁻³ µS y⁻¹. This is comparable also to the environmental impact statement study on the transport of spent nuclear fuel to the Yucca Mountain deep geological disposal facility in the (U.S. DOE, 2002) which considers that the average dose for members of the public will be 0.005 µSv·y⁻¹.

As the vehicle is generally in movement (Fig. 2), the dose rate produced at a point (P) by a radioactive source located at a point (C) will be:

$$D(P) = K \frac{A}{d_1^2} \quad A = \text{Activity of source} \quad (1)$$

Likewise, the dose rate produced at (B) will be:

$$D(B) = K \frac{A}{d_2^2} \quad (2)$$

As these may be related, the following will be obtained:

$$D(P) = D(B) \frac{d_2^2}{d_1^2} \quad (3)$$

If d_2 is considered to be equal to 1 metre, the dose rate at (B) becomes the Transport Index (TI); in other words:

$$D(P) = \frac{IT}{d_1^2} ; \quad d_1^2 = v^2 \cdot t^2 + b^2 \quad (4)$$

Consequently, the dose (D) at a point (P) produced by the moving source may be obtained depending on the Transport Index (IT) and the distance between the radioactive material and this point. Furthermore, and with a view to maintaining dimensional coherence, a constant (K_D), with a value of (1 m^2), is introduced in the equation. Consequently, the dose produced by the moving source over the entire trajectory will be obtained by integrating the following expression:

$$\int dD(P) = \int_0^\infty K_D \cdot IT \left/ \int (v^2 \cdot t^2 + b^2) dt = K_D \cdot IT \left/ b \cdot v (\arctg v \cdot t / b) \right] \quad (5)$$

$$\text{And as a result the following will be obtained: } D(P) = \pi \cdot K_D \cdot IT / b \cdot v \quad (6)$$

$$\pi = 3.1416$$

$$K_D = \text{Constant} (1 \text{ m}^2)$$

$$IT = \text{Transport Index, level of radiation at one metre from the transport unit, } (\mu\text{Sv/h})$$

$$b = \text{distance to the vehicle (m)}$$

$$v = \text{speed of vehicle (m/h)}$$

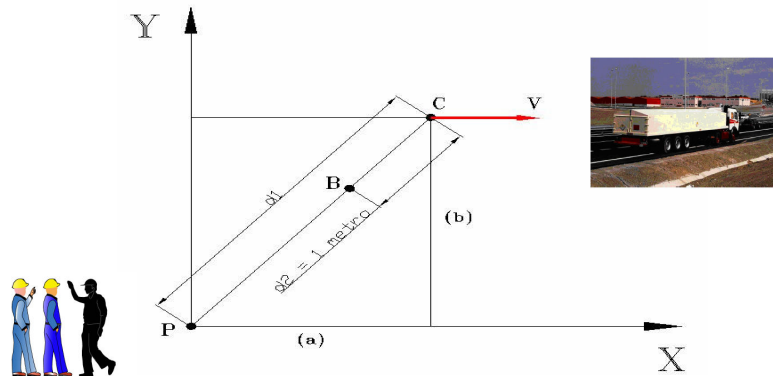


Figure 2 - Dose produced at a point by a moving vehicle transporting radioactive material

This expression accurately calculates the gamma radiation dose that would be received by a group of people located at a known distance from a transport vehicle travelling at a fixed speed.

Although a generalised solution is adopted, without taking into account the precise proximity of the group to the transport vehicle or the variable speed of this vehicle, it is of interest to learn of the margin of error in the study performed.

If we focus on the impact generated on the general public (Table I), taking into account the following factors:

1. the total dose of $46.64 \mu\text{Sv}\cdot\text{y}^{-1}$ obtained, calculated on the basis of the radiation level at a distance of one metre from the vehicle (or $5\mu\text{Sv}\cdot\text{h}^{-1}$, as the weighted average for all the types of transport on the different routes),
2. a speed of 90 km./h (which is in keeping with the road safety regulations for this type of haulage),
3. an impact distance of 1,000 metres (a distance within which might be located the bulk of the population of a major city such as Madrid, Barcelona or Zaragoza, which are significant cities through which such transport operations pass),

then, the following will be obtained:

$$D(P) = 3.1416 \times 46.64 / 1000 \times 90000 = 1.6 \cdot 10^{-3} \mu\text{Sv}\cdot\text{y}^{-1} \quad (7)$$

Which is very similar to the dose obtained previously (Table I) of $(1.1 \cdot 10^{-3} \mu\text{Sv}\cdot\text{y}^{-1})$.

We are aware that with this last calculation certain errors may have been made as regards distances, the constant speed of the vehicle and the location of the bulk of the population at the moment of passing of the vehicle. Nevertheless, as has already been pointed out, the objective pursued has been to compare differences between the initial treatment of the data and its calculation using a more scientific process. Furthermore, it has been observed that the two sets of data are similar.

The probability of the most exposed individual suffering serious illness (cancer), the detriment to health resulting from exposure to ionising radiation amounts to $2.31 \cdot 10^{-7}$, this probability being approximately 10^{-12} (Table I) if considered at national level. This figure is obtained as the quotient between the dose received by the general public and the probability of death by cancer of 5% per Sievert in a population of all ages, as long as the dose and dose rate are low (Publication ICRP, 1999).

In the epidemiological study of the possible effects of ionising radiations arising from the operation of the Spanish nuclear fuel cycle nuclear and radioactive facilities on the health of the population living in areas surrounding such installations (Nuclear Safety Council, 2010), the “effective dose” is proposed as an indicator of exposure, since this parameter brings benefits in a study of far-reaching scope and spectrum and since furthermore several external exposure paths for ionising radiations are identified, along with others such as liquid and gaseous effluents that may be incorporated into the human organism.

In this paper, and since only external exposure to ionising radiations is dealt with, “distance” is proposed as the main indicator on the basis of the attenuation achieved in the process of emission, this being, in the opinion of the authors, the most appropriate approach in this case.

Table I - Radiological impact associated with the transport by road of radioactive material.

RADIOLOGICAL IMPACT ASSOCIATED WITH THE TRANSPORT BY ROAD OF RADIOACTIVE MATERIAL IN SPAIN (2007)							
ROUTES	Total Dose Impact ($\mu\text{Sv. y}^{-1}$)	Dose to MOST exposed individual ($\mu\text{Sv. y}^{-1}$)	Dose to Public (impact on route) ($\mu\text{Sv. y}^{-1}$)	Dose to Public (national impact) ($\mu\text{Sv. y}^{-1}$)	Detriment to health (MOST exposed individual)	Detriment to health (public on route)	Detriment to health (national impact)
FROM NUCLEAR POWER PLANTS TO EL CABRIL RADIOACTIVE WASTE DISPOSAL FACILITY (radioactive waste)	42005	4.63	1.44 E-03	9.81E-04	2.31E-07	7.23 E-11	8.16 E-12
FROM JUZBADO FUEL ASSEMBLY MANUFACTURING FACILITY TO NUCLEAR POWER PLANTS	1592	0.24	9.43 E-05	3.72 E-05	1.23E-08	4.73 E-12	1.86 E-12
FROM NUCLEAR POWER PLANTS TO MADRID (equipment and materials)	2218	0.46	4.35 E-05	4.53 E-05	2.31E-08	1.30 E-11	2.59 E-12
FROM NUCLEAR POWER PLANTS TO FRONTIER, JUNQUERA (equipment and materials)	521	0.10	1.36 E-05	1.22 E-05	5.00E-09	6.79 E-13	6.07 E-13
BETWEEN NUCLEAR POWER PLANTS (equipment and materials)	303	0.12	6.96 E-05	7.07 E-06	6.33E-09	1.16 E-12	3.53 E-13
OVERALL	46.64	1.36	N/A	1.10 E-03	6.80 E-08	N/A	5.40 E-11

Overall dose impact: Value obtained from the contribution of all the shipments performed on all the routes.

Dose to most exposed individual (overtaking): 15 seconds x 3 overtaking manoeuvres on route: the individual is assumed to travel on the route at the same time as the shipment is performed.

Dose to public, impact on route: Consideration is given to the population of all ages resident in the provinces through which the shipment passes.

Dose to public, national impact: Population of all ages in the national environment, subjected to impact.

Health detriment (death by cancer): the average value as regards the probability of death by cancer is 5% per Sievert in a population of all ages or 5×10^{-8} per μ Sievert.

Although the units for description of the overall impact are proposed in equivalent dose (μ Sv), it would be more correct to express them in units of exposure or absorbed dose (μ Gy), since the dose may or may not be acquired by human beings (depending on whether or not they are in the area of exposure); however, as has been indicated, in the case of gamma emission the exposure is similar to absorbed dose and the same as equivalent dose. Consequently, as the values for the measurement of radiation level one metre from the transport vehicle are proposed in units of equivalent dose, those obtained in this study will in all cases be expressed in these units.

6. Radiological impact calculation programme

As a final contribution, a computer application for the treatment of the data studied is presented, along with a summary sheet: “Radiological Impact Associated with the Transport by Road of Radioactive Material in Spain”.

This is perhaps the most interesting part of the work and marks a step forward in the study of these impacts, serving to complement the legally required documentation for this type of transport operation.

The radiation level at a distance of one metre from the transport vehicle being known, and with the route selected (Fig. 3) - which are data supplied by the shipper - the associated radiological impacts can be obtained (Fig. 4).



 RADIOLOGICAL IMPACT ASSOCIATED WITH THE TRANSPORT OF RADIOACTIVE MATERIAL BY ROAD IN SPAIN			
			
INPUT THE LEVEL OF RADIATION AT A DISTANCE OF ONE METRE FROM THE TRANSPORT VEHICLE (uSv/h)	<div style="border: 1px solid black; padding: 5px; display: inline-block;">10</div>		
SELECT THE DESIRED ROUTE			
<div style="border: 1px solid black; padding: 2px; margin-bottom: 2px;">ALMARAZ NPP-CABRIL</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 2px;">ASCO NPP-CABRIL</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 2px;">VANDELLOS NPP-CABRIL</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 2px;">COFRENTES NPP-CABRIL</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 2px;">GAROÑA NPP-CABRIL</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 2px;">TRILLO NPP-CABRIL</div>	<div style="border: 1px solid black; padding: 2px; margin-bottom: 2px;">JUZBAGO-COFRONTES NPP</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 2px;">JUZBAGO-ALMARAZ NPP</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 2px;">JUZBAGO-ASCO NPP</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 2px;">JUZBAGO-VANDELLOS NPP</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 2px;">JUZBAGO-TRILLO NPP</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 2px;">JUZBAGO-GAROÑA NPP</div>	<div style="border: 1px solid black; padding: 2px; margin-bottom: 2px;">COFRENTES NPP-MADRID</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 2px;">ALMARAZ NPP-MADRID</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 2px;">ASCO NPP-MADRID</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 2px;">VANDELLOS NPP-MADRID</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 2px;">TRILLO NPP-MADRID</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 2px;">GAROÑA NPP-MADRID</div>	<div style="border: 1px solid black; padding: 2px; margin-bottom: 2px;">COFRENTES NPP-JUNQUERA</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 2px;">ALMARAZ NPP-JUNQUERA</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 2px;">TRILLO NPP-JUNQUERA</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 2px;">ALMARAZ NPP-TRILLO NPP</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 2px;">COFRENTES NPP-GAROÑA NPP</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 2px;">ASCO NPP-VANDELLOS NPP</div>

Figure 3 - Data input sheet





 RADIOLOGICAL IMPACT ASSOCIATED WITH THE TRANSPORT OF RADIOACTIVE MATERIAL BY ROAD IN SPAIN		
		
ROUTE:	ASCO NPP-CABRIL	 
TIME IN ROUTE:	10 Hours	
EXPOSED POPULATIONS	Tarragona-Castellón-Valencia-Cuenca-Ciudad Real-Jaén-Córdoba	
OVERALL RADIOLOGICAL IMPACT (uSv):	100	
MOST EXPOSED INDIVIDUAL DOSE (uSv):	2,9	
DETRIMENT OF HIS HEALTH:	1,45E-07	
CONTRIBUTION TO POPULATION ON ROUTE (uSv):	1,07E-03	
NATIONAL CONTRIBUTION DOSE (uSv):	1,37E-04	
HEALTH DETRIMENT:	6,84E-12	

Figure 4 - Results sheet

7. Conclusions

As an initial conclusion, it has been demonstrated that ionising radiations generated by the transport of radioactive materials from the nuclear fuel cycle in Spain are not significant in terms of producing adverse effects for human health. Furthermore, the annual overall radiological impact is very low and has a negligible adverse impact on health.

Secondly, the routes used for this type of transport operations cover almost the entire national territory. Of the 24 existing routes, three are particularly active in terms of the density of shipments and of the significance of the associated radiological burden, (these being the Extremadura A-5, Levante A-3 and Aragón A-2 motorways). This increases the associated radiological risk since the density of the traffic on these routes will be greater.

8. Acknowledgements

Our thanks go to the personnel of the radiological protection organisations of the Spanish nuclear power plants and to the members of the Tecnatom prevention service, who have proposed many of the data relating to the transport operations performed.

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